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Implementation of Bridgeless Cuk Power Factor Corrector with Positive Output Voltage

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Abstract: ***A single-phase bridgeless Cuk ac/dc power factor correction (PFC) rectifier with positive output voltage is designed. For low output voltage product applications, the rectifier is designed to convert high input voltage to low output voltage. Due to no bridge diodes required and thus decreased input conduction losses, the rectifier efficiency can be improved. The proposed rectifier operates in discontinuous conduction mode, and the current-loop circuit is hence not needed. In addition, only a single switch is used in the rectifier to simplify the control circuit design. A simple translation method to have the positive output voltage in the Cuk converter is presented in the rectifier to reduce the component counts and the cost. The operational principles, steady-state analysis, and design procedure of the rectifier are analysed in detail.***

Keywords: DC–DC converter, Power factor correction, zcs turn on of switch, zcs turn off of diode

1. Introduction

The current flows through bridge diodes and the power switch S_1 during the switch on-time and through bridge diodes and the output diodeD_0during the switch off-time. Thus, during each switching cycle, the current flows through three power semiconductor devices. As a result, the significant conduction loss caused by the forward voltage drop across the bridge diodes degrades the converter's efficiency, particularly at low line input voltage. To reduce the conduction losses, the number of semiconductor devices should be reduced in the current path.

Some methods are introduced to reduce conduction losses in Cuk converter. Bridgeless PFC circuits where the current flows through a minimum number of switching devices compared with the conventional PFC rectifier. Accordingly, the converter conduction losses can be significantly reduced, and higher efficiency can be obtained and cost savings.

The Cuk and SEPIC converters have negative output voltages. Therefore, the extra requirement is an inverse amplifier circuit to translate the negative into the positive voltage The additional inverse amplifier circuit needed.thus increases the cost. obtain the positive output voltage in cuk converter without the inverting amplifier circuit, we transfer the polarity of all the components

2. Topology of the Converter

The Cuk converters have negative output voltages. Therefore, the extra requirement is needed. An inverse amplifier circuit to translate the negative into the positive voltage. The additional inverse amplifier circuit needed, thus increases the cost.

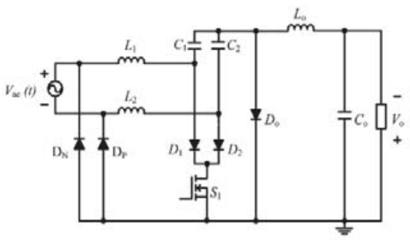

Figure 2.1: BridgelessCuk PFC Rectifier with Negative Output Voltage

Fig.2.1 shows the initial bridgeless Cuk PFC rectifier,which has a negative output voltage, like the existing Cuk PFC rectifier. As noted, for this circuit, an inverting circuit is needed to transfer the negative to the positive output voltage is still required for analog feedback control, as shown in Fig. 2.2 To obtain the positive output voltage without the inverting amplifier circuit, we have to transfer the polarity of all the components in Fig. 2.1 in the way as shown in Fig. 2.3 .

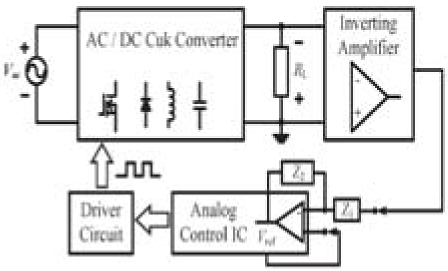

Figure 2.2: Blocking diagram of the conventional Cuk PFC circuit (with negative output voltage).

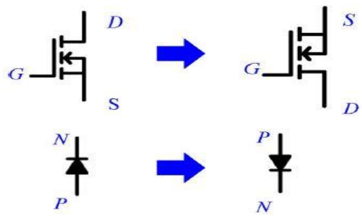

Figure 2.3: Transferring the polarity of all components (switch and diodes)

By transfering the polarity of all the components we can obtain the bridgeless Cuk PFC rectifier with positive output voltage.

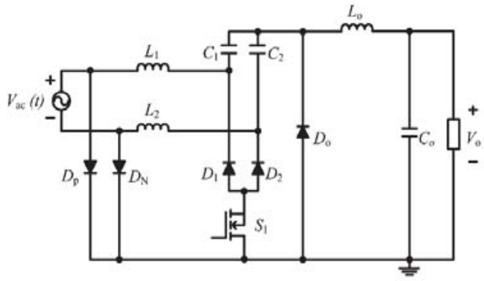

Figure 2.4: BridgelessCuk PFC Rectifier With Positive Output Voltage

Thus, the feedback control circuit is simpler, and the cost can be also reduced, as compared with the conventional feedback control circuit shown in Fig. 1.2 although the power switch employed in the circuit is floated with a high-side gate driver needed.

Steady state analysis assumptions

Before analyzing the rectifier, the analysis of the circuit supposes that the converter is operating at steady state with the following assumptions.

1) The ON-state resistance R_{DS} and parasitic capacitances of the main switch S_1 and the forward voltage dropsV_d of the diodes are neglected.
2) The input capacitances are large enough such that, during a switching period T_s , their voltages are considered to be constant.
3) The output capacitor C_o is sufficiently large that the output voltage is considered to be constant.
4) The proposed converter is operated in DCM.
5) Due to symmetry of the circuit, it is sufficient to analyze the circuit during the positive half-cycle of the input voltage

3. Operation of the Converter

The converter is operated in discontinous conduction mode.Operation of the converter can be explained through three modes.

Mode 1 [$t_0 - t_1$] :

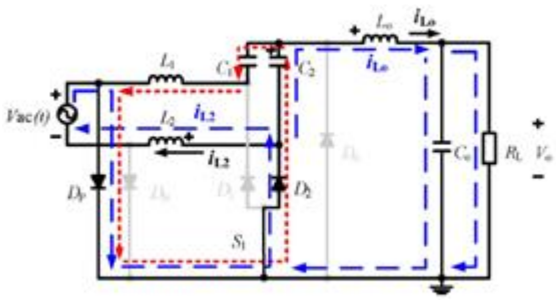

Figure 3.1: Equivalent circuit in mode I (switch S_1 is turned on).

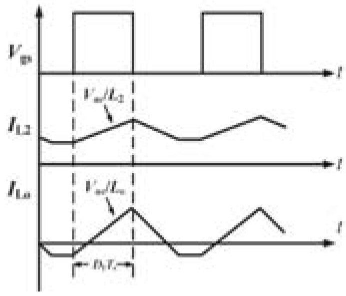

Figure 3.2: Theoretical DCM waveforms during one switching period $T_S$in mode I (switch S_1 is turned on)

This mode starts when switch S1 is turned on, as shown in Figs.3.1and 3.2 Input inductor L_2 starts to charge linearly in slope of$\frac{Vac\,(t)}{L_2}$and diode D_P is forward biased by the inductor current L_2. The voltage acrossL_0 is equal to V_{ac} (t) thus, L_0 increases linearly in slope of $\frac{Vac\,(t)}{L_0}$ .The inductor currents of L_0 and L_2 during this mode are given by$\frac{di_L}{dt} = \frac{V_{ac}\,(t)}{L_n}$ n=2, Accordingly, the peak current through the active switch is S_1 given by

$$I_{(S_1),PK} = \frac{Vm}{L_e} * D_1 * T_S$$

where$V_m$is the amplitude of the input voltage $Vac(t)$,$D_1$is the switch duty cycle, and L_e is the parallel combination of inductors L_1 ,L_2 and L_o

Mode 2 [$t_1 - t_2$] :

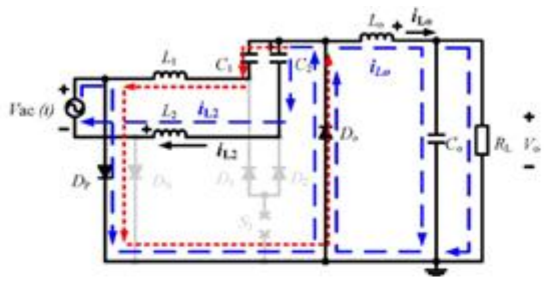

Figure 3.3: Equivalent circuit in mode II (switch $S_1$is turned off)

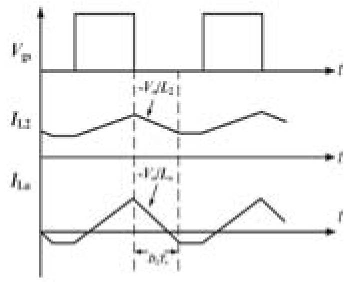

Figure 3.4: Theoretical DCM waveforms during one switching period $T_S$in mode II (switch S_1 is turned off)

This mode starts when switch S_1 is turned off, D_o is turned on, simultaneously, as shown in fig 3.3, fig 3.4 Input inductor L_2starts to discharge linearly in slope of $\frac{Vac\,(t)}{L_2}$.And diode $D_P$is forward biased by the inductor current i_{L2}. The voltage across $L_o$is equal to V_o; thus, i_{L2} decreases linearly in slope of $\frac{V_o}{L_o}$. Note that diode $D_o$is turned off at zero current.

The inductor currents of L_2 and L_o during this mode are given by

$$\frac{di_{L2}}{dt} = -\frac{V_{ac}(t)}{L_n}$$

$$\frac{di_{L0}}{dt} = -\frac{V_0(t)}{L_n}$$

Mode 3 [t_2– t_3] :

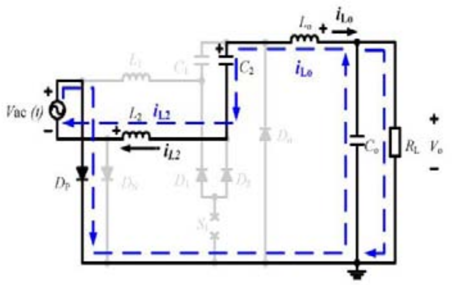

Figure 3.5: Equivalent circuit in mode III (switch S_1 is turned off)

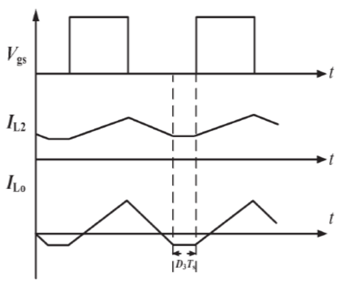

Figure 3.6: Theoretical DCM waveforms during one switching period T_S in mode III (switch S_1 is turned off)

During this interval, only diode D_P conducts to provide a path for L_2, as shown in Fig. 3.5. Accordingly, the inductors L_2 and L_0 in this interval behave as constant current source. Thus, the voltage of inductors L_2 and L_0 is zero. Capacitor C_2 is being charged by the inductor current i_{L2} and the energy of capacitor C_0 is released to load.This is a freewheeling mode. The theoretical waveforms in this mode are shown in Fig. 3.6 This mode lasts until the start of a new switching period. The turn off time of the switch and the output diode is given by

$$T_{off} = T_S - t_{on} - t_{don}$$

where t_{on} is the conducting interval of switch S_1, and t_{don} is that of the output diode D_0. The normalized length of mode II period can be obtained as follows:

$$D_2 = \frac{D_1}{M} sin\omega_t$$

where ω is the line angular frequency, and M is the voltage conversion ratio (M = $\frac{V_O}{V_{in}}$).

4. Simulation of Bridgeless Cuk PFC Rectifier with Negative Output Voltage

Design parameters and simulation circuit of Bridgeless Cuk PFC rectifier with positive output voltage

Parameters	*Values*
Input Voltage	(90-130) V_{rms}
Switching Frequency,f_s	50 KHz
Input Inductor,L_1& L_2	1mH
Output Inductor,L_0	22µH
Capacitor,C_1 & C_2	.1uf
Output Capacitor	1000uf

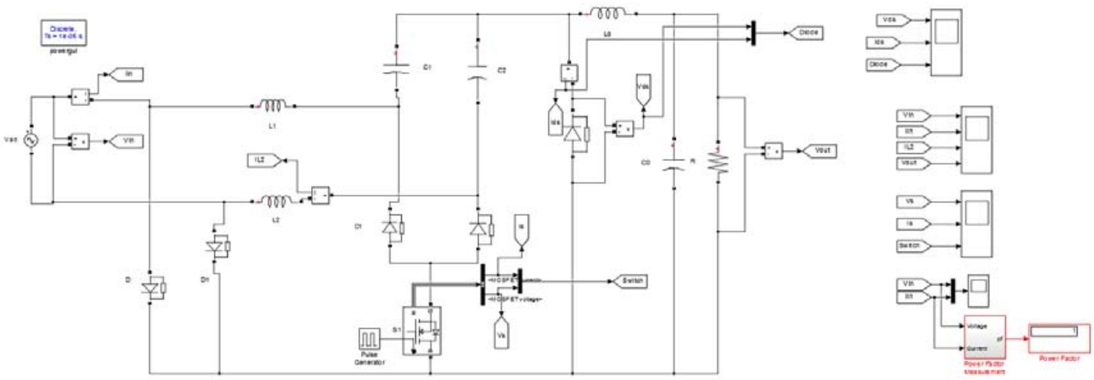

Figure 4.1: Simulation of Bridgeless Cuk PFC rectifier with positive output voltage

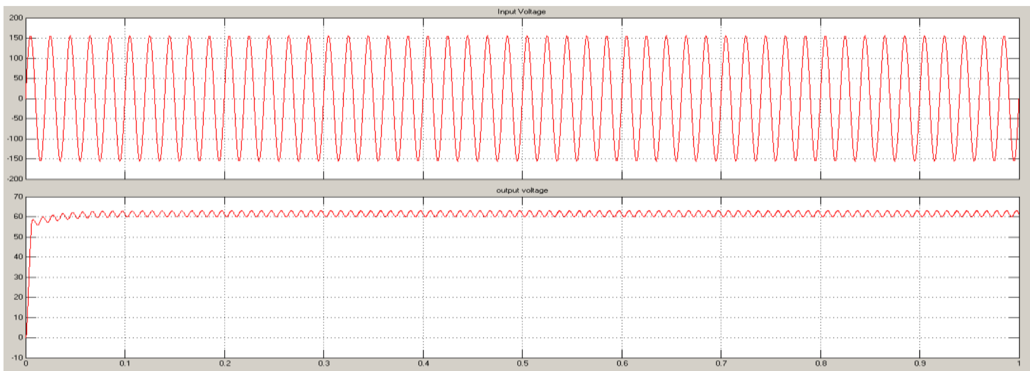

Figure 4.2: Simulation Result of Bridgeless Cuk PFC rectifier with positive output voltage

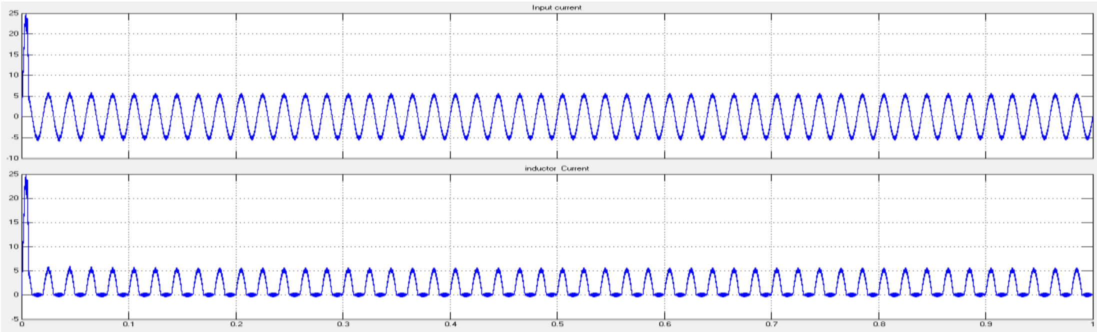

Figure 4.3: Simulation result : Input current and Inductor current

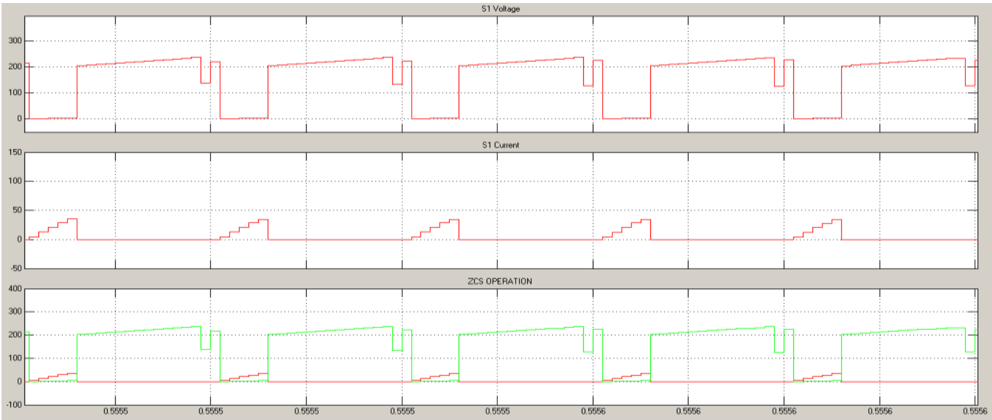

Figure 4.4: Simulation result :ZCS turn on of switch

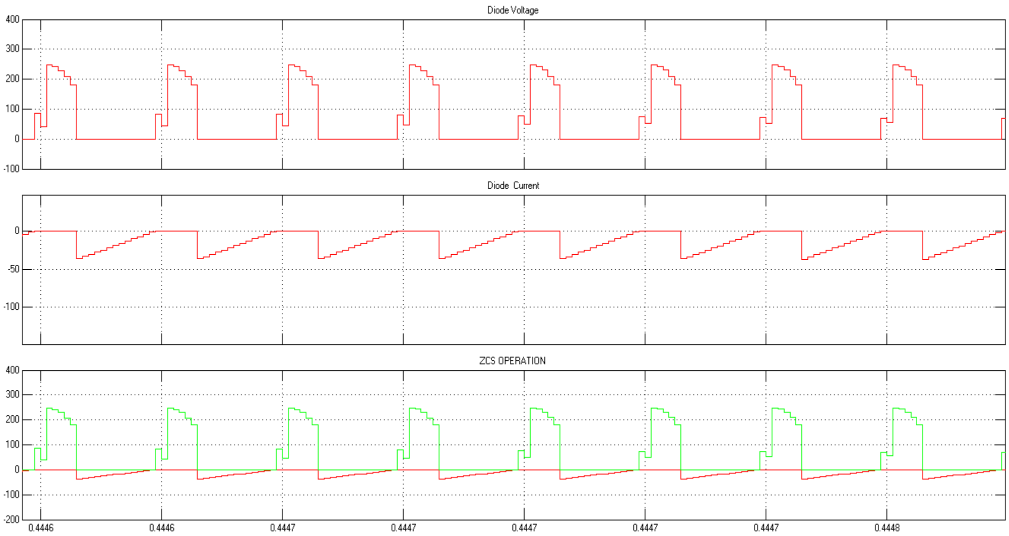

Figure 4.5: Simulation result :ZCS turn off of diode

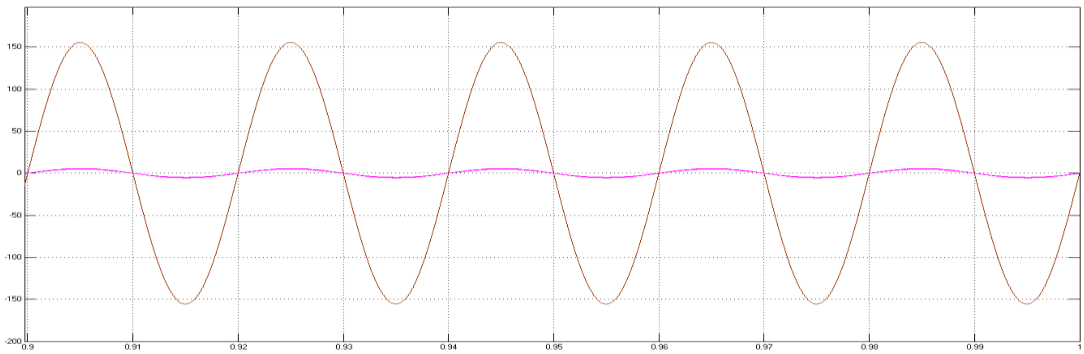

Figure 4.6: Simulation result:Unity power factor(voltage and current are in phase)

5. Hardware Implementation Bridgeless Cuk PFC Rectifier with Positive Output Voltage

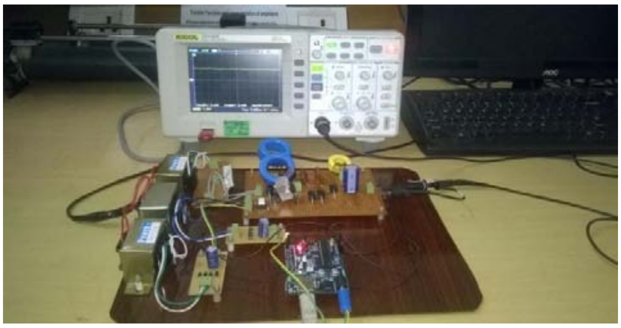

Figure 4.7: Hardware implementationof Bridgeless Cuk PFC rectifier with positive output voltaare made

6. Conclusion

The Cuk PFC rectifier with positive output voltage has been analyzed . The simulation results have shown good agreements with theBpredicted waveforms analyzed in the converter. The PF of the circuit has unity above at all the specified input and output conditions. Moreover, with higher efficiency and high PF, the Cuk PFC rectifier with positive output voltage is able to be applied to most of the consumer electronic products of 150-Wrating in the market. In addition, with only a single switch employed, the implemented system control circuit is simple to achieve high PF by applying any pulse width modulation control integrated circuit.

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